Spectrum and Technology

This note is addressed to my colleagues in the FCC TAC. The purpose is to share both information and opinions regarding our discussion on spectrum use.
As a resident of California, here is my political disclaimer: since a vast number of my fellow residents have veered into public politics, if there are overtones of political debate in this document, you can blame it on osmosis.

Technology

As a believer in the power of technology, my teams[1] have built "proof of concept" software/cognitive radios and space-time adaptive radio systems for years. However the commercial implementation of these technologies have taken many years of refinements, simulations, experiments, persuasion and down-to-earth economics at the network level to draw them into the marketplace.

The three major building blocks of all these systems were:

a) r.f. plumbing at the front end (e.g. wideband radio front end to capture the full spectral allocation in one piece of hardware, quite unlike conventional channelized and tuned radios; multiple antenna and r.f. subsystems to bring in/out multiple (but uncorrelated) signals into the signal processing farm in (b))
b) the adaptive/cognitive part of the system, usually implemented in DSP or FPGA, where the radio was able to decipher wanted and unwanted signals (i.e. using "signatures") , using filtering, digital channelization, and creating as much information as possible to facilitate ANY form of discrimination (i.e. in frequency, space and time) between the signals of desired users, (known) undesired users and unknown users or noise sources. The less predictable the undesired or unknown, the more complex was the processing. In the context of our current discussion, this is where most of the innovation and invention is the essence of the debate, as far I understand. I refer to this issue below as the "surprise" issue.
c) a third area can actually yield a LOT of gain, even if (b) is not done well: a simple example: when a cellular phone hands over from one cell to another, the trigger today is a window of signal strength and timeframe parameters which, when satisfied, calls for a handover. If you were able to use each base station as a spectroscope, and also to dynamically tie in the intelligence of the quality and network load from the signaling system, you have a very efficient, interactive, adaptive scheme, which results in less dropped calls, and less power transmission loss in the network. This is in the class of network-based processing and

[1] At Bell Labs and at a wireless technology start-up

intelligence, somewhat different than purely radio based solutions in (b).

Homogeneous systems[2]

It should be noted that most of the work referred to above was to enhance the performance of networks with known classes of interferers, and pretty good signature of what the desired and undesired users are. TDMA, GSM and CDMA are systems where there is plenty of work in the literature and field trials (and a few field deployments).

I cannot claim that the barrier was spectrum in implementing these for cellular networks, but it was the complex process of reducing these technologies to practice, and to get them adopted into commercial networks to support viable services. There is no doubt that if a wireless network is already built, like any legacy system, to add or innovate in ways that replaces or threatens the existing base of equipment and services is always difficult, but has been done.

However I have seen spectacular technical performance on new systems where room for *implementation* of innovation is easier, initially in experimental spectrum and subsequently in licensed spectrum. Using adaptive spatial processing, software radios, one can set exceptional network-level benchmarks in spectral efficiency.

Where new spectrum techniques and policy are particularly important (from a technology perspective) is where new networks, new services and innovation for new or competitive services and product business models can be stimulated. This comment pertains to both licensed spectrum and license-exempt spectrum.

Service Reliability and Availability

As we discuss our thoughts on the technology, it should be noted (as some of you have observed) that certain classes of service are deemed so mission critical that the level of availability, latency, assured bandwidth and frame or bit error rates throughout a service area, mandate licensed and dedicated spectrum.

There may be many classes of service where by allowing less stringent performance criteria, spectrum use can be far more flexible. I am not suggesting that we do open-ended market research on new services, but allow that there are and will be many less demanding (in terms of mission-critical criteria) but valuable services, worthy of deployment. From a technology

[2] A wireless network where all the devices and the network share the same protocol, with no other waveforms in the spectrum band: best example is a cellular network operating in licensed spectrum

perspective, if we can trade off rapid innovation and rapid expansion of services and products versus the many years that conventional radio systems take to get to market, perhaps a slight compromise in performance can be measured, and shown to be quite acceptable.

Heterogeneous systems[3]

I believe that if any problem is stated well, then the viability of a technology solution to the problem can be assessed. Often this may not mean finding the answer, but more likely one's experience will give enough of an assessment of how much resources and innovation (if not invention) may be required. (Does not mean *any* problem can be solved, however).

It seems that the ability to discriminate/reject *dissimilar* signals in the same piece of spectrum is a much more complex problem than signals which have common fingerprints. However, unless we get more specific (i.e. the characteristics of LAN radio propagation are vastly different from WAN radio propagation; different frequency bands have different loss and barrier penetration characteristics; different modulation schemes, when combined with implementations of (b) or (c) above yield a simpler solution space than conventional radios) it is very difficult to give sufficient guidelines for the policy-makers that we serve to act on our guidance.

(In this context, I have attached an excel spreadsheet which was a response to one of the breakout sessions we had at the last TAC meeting in July: the theme was what measurements one would need to assist in defining metrics for spectrum sharing: some of you will already have seen this).

Surprises in radio systems

As described above, the main issue at hand is what is the impact of "surprises"[4] to a radio network with the presence of many users, all of whom have an equal right to use the spectrum, but also have to have a level of politeness protocols such that some minimum level of availability and quality of service is possible. Ongoing research on items (a), (b) and (c) will continue to yield performance gains. I would encourage any experimentation, proof of concept, simulations and network-level evidence on how heterogeneous systems behave under load.

The empirical studies of Bluetooth-WiFi (IEEE 802.11 standards) I have seen illustrate that there are enough catastrophic scenarios which can be found regarding coexistence, and yet neither technology has stopped in its tracks.

---

[3] Heterogeneous radio systems: most common example is the use of the very same spectrum for WiFi Wireless LANs, Bluetooth PANs, microwave ovens and cordless phones in the 2.4 GHz ISM band.

[4] Surprises: the appearance of noise or interference from another user of the spectrum in realtime which requires action by the users or the network in a dynamic and timely fashion to ensure continuity and quality of service for both parties

Despite some attempts, there is no commonality in signaling, protocol or physical layer that has been viable to allow polite coordination between such disparate systems. I have seen very little research on other heterogeneous systems occupying the same spectrum for other systems.

The call to action to the research community from the TAC is probably along the lines of showing how spectrum could be used without a pre-mandated common set of rules, or what minimal set of rules which do not constrain either service or product implementations would be viable. A basic principle is to ensure that the solution supports an ongoing path of innovation. The other piece which will be of tremendous value from such research is an estimation of the time to market for these solutions.

Spectrum: licensed, license-exempt and experimental

The FCC has spectrum allocations classed broadly in the licensed and license-exempt areas. It should be noted that the FCC grants a vast number of experimental licenses for innovators to utilize spectrum (with appropriate restrictions on technical and spatial parameters, to respect the needs of the current licensed owners).

My projects have benefited time after time by the efficient and effective policy which manages such licenses, and has many times made available spectrum for many different uses to test out innovative pre-commercial ideas. My team and many others have (with permission) encroached on the spectral property of licensees of spectrum, taking advantage of the time, space and flexibility of spectrum which is used but underutilized.

One question in my mind is that if we believe, as many members of the TAC do, that there is technology which would be able to operate in an open market/innovative way, why do we not encourage they use the experimental license vehicle to its full for innovators to demonstrate their capabilities. The more information the FCC can gather, the better the policy decisions would be in serving the public interest.

We have seen a lot of spectrum which has been allocated and underutilized. I would hope that advocates of “cognitive”/”innovative” radios would move forward quickly, demonstrate their concepts in experimental spectrum and allow the regulators to allocate new spectrum based on some level of knowledge that these new allocations will be viable.

So what was this about?

My purpose was to share some experiences (especially for the non-radio TAC members) and to offer some ideas on how we can challenge the technology community to offer and demonstrate viable solutions, as well as to give us ideas on timeframes for spectrum sharing. The objective is to get sufficient data such that regulators and public policy makers have a viable basis for their decisions. Also I wanted to indicate that in licensed spectrum, with homogeneous radio systems, there are many tools to improve the performance of wireless systems today.